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## MATHEMATICAL MODEL FOR CALCULATING THE HEATING OF GLASS-KREMNEZIT MATERIAL

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A technology and a facility for cost-effective fabrication of glass-kremnezit based on modular production methods have been developed. A mathematical model is proposed for calculating heat transfer. This model makes it possible to determine the required thicknesses of the thermal insulation for the covered heater and the shapes for which the heat losses into the surrounding atmosphere during continual operation of the heater are reduced to a minimum.

Glass-kremnezit is a new-generation ornamental–facing material which possesses longevity, high mechanical strength, chemical resistance, high durability, heat resistance, and good ornamental properties. Glass-kremnezit replaces the traditional expensive stone (granite, marble) and can be used as an ornamental-protective glass ceramic material. It can be used for facing interior and exterior walls of buildings and small architectural structures in cities (parks, stadiums, general-use spaces).

The granular–powder technology proposed by A. S. Bykov is used to manufacture glass-kremnezit in the form of slabs of different sizes and configurations.

Wastes from the glass industry, sand, colored granular material, and various additives are used to obtain glass-kremnezit. A granular–powder mixture of these materials, loaded into heat-stable molds, is heated unilaterally in a specially designed electric furnace up to the batch melting temperature.

We have developed a technology and a facility for cost-effective fabrication of glass-kremnezit (RF Patent No. 55767).

A modular principle is proposed for obtaining glass-kremnezit. A module consists of several covered heaters suspended on a mobile car and the same number of thermally insulated molds placed on mobile cars. A car loaded with batch and containing the thermally insulated molds is moved into a position below the heaters. The heaters are lowered onto the molds, by means of a mechanism which moves the heaters up or down, and switched on. When the surface of the batch reaches a prescribed temperature, the heaters are raised up, the car with the molds is moved to the annealing section, and a new car containing molds loaded with batch is positioned under the heaters. Next, the heaters are once again lowered and the process of heating the batch in the molds is repeated.

The basic problem of the heat-transfer calculation is to determine the required thicknesses of the thermal insulation of the covered heater and molds that minimize the heat losses into the surrounding atmosphere while the heater is continually operating.

**Mathematical Model for Calculating Heat Transfer.** A diagram of the technological block consisting of a mold (layers *3 – 8*), cover, and heater is displayed in Fig. 1.

A three-dimensional heat-conduction equation is solved to determine the temperatures in the cover and mold (together with the batch) separately [1]:

$$\rho c \frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right),$$

where ñ is the density of the materials, kg/m$^3$; $c$ is the specific heat capacity of the materials, J/(kg · K); $T$ is the temperature, K; $\tau$ is the time, sec; $x$, $y$, and $z$ are the coordinates, m; and, $\lambda$ is the thermal conductivity, W/(m · K).

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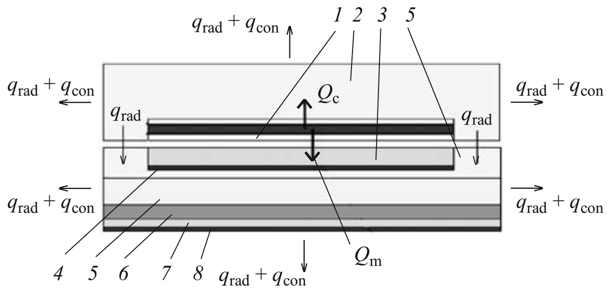


**Fig. 1.** Diagram of the technological block: *1* ) heater; *2* ) cover; *3* ) batch; *4* ) sand; *5* ) chamotte brick; *6* ) supersil; *7* ) asbestos cement; *8* ) steel plate; $q_{rad}$ and $q_{con}$ ) radiant and convective heat flux densities; $Q_m$ and $Q_c$ ) heat fluxes from the heater into the mold and cover, respectively.

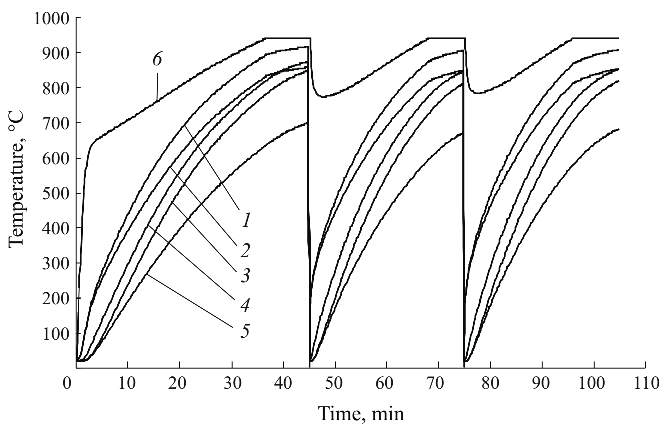


**Fig. 2.** Temperatures at characteristic points of the mold versus time: *1*, *2*, *3*, *4*, and *5* ) $T_1$, $T_2$, $T_3$, $T_4$, and $T_5$, respectively; *6* ) $T_h$ .

The average temperature of the heater is calculated from its heat balance equation:

$$\rho_h c_h V_h \frac{\partial T_h}{\partial \tau} = Q_{el} - Q_h,$$

where $\rho_h$ is the density of the heater material, kg/m$^3$; $c_h$ is the specific heat capacity of the heater material, J/(kg · K); $V_h$ is the volume of the heater, m$^3$; $T_h$ is the average temperature of the heater material, K; $Q_{el}$ is the electric power of the heater, W; and, $Q_h$ is the thermal power radiated from the heater into the cover and mold, W.

The heat flux schemes inside and outside the technological block are presented in Fig. 1. The densities of the radiant and convective (differing for horizontal and vertical surfaces) heat fluxes directed into the environment on the exterior surfaces of the cover and mold are determined using the local temperatures of the exterior surfaces.

*Example of the Calculation of the Technological Process Parameters*. We shall consider the production of a 0.8 × 0.8 × 0.02 m glass-kremnezit slab in a 1 × 1 × 0.1 m mold with a 1 × 1 × 0.08 m cover. The heater power is 38 kW.

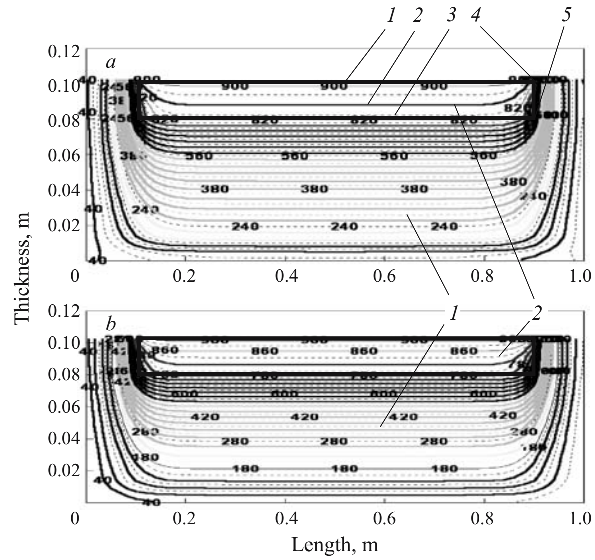


**Fig. 3.** Temperature field (°C) in mold No. 1 45 min (*a*) and in mold No. 2 30 min (*b* ) after heating starts: *1* ) mold; *2* ) glass slab; *1 – 5* ) characteristic points of the mold.

When the temperature of the heating element reaches 940°C the heater is disconnected from the electric grid. A relay is used to maintain a constant temperature.

The initial temperature of the cover, mold, and heater were assumed to be 20°C. The thermophysical properties of the materials were as follows [2]:

glass: $\rho$ = 2700 kg/m$^3$, $c$ = 1000 J/(kg · K), $\lambda$ = 1.76 W/(m · K);

chamotte brick: $\rho$ = 400 kg/m$^3$, $c$ = 840 J/(kg · K), $\lambda$ = 0.3 W/(m · K);

sand: $\rho$ = 1520 kg/m$^3$, $c$ = 920 J/(kg · K), $\lambda$ = 0.81 W/(m · K);

steel plate: $\rho$ = 7800 kg/m$^3$, $c$ = 470 J/(kg · K), $\lambda$ = 58.0 W/(m · K);

asbestos cement slab: $\rho$ = 960 kg/m$^3$, $c$ = 855 J/(kg · K), $\lambda$ = 0.09 W/(m · K);

supersil: $\rho$ = 150 kg/m$^3$, $c$ = 582 J/(kg · K), $\lambda$ = 0.25 W/(m · K);

heater: $\rho$ = 500 kg/m$^3$, $c$ = 1045 J/(kg · K).

The dependences of the temperatures at characteristic points of the mold on the time elapsed from the start of the technological process are presented in Fig. 2 (the indices on the temperatures correspond to a number of a point in Fig. 3, the index "h" refers to the temperature of the heater), and the temperature field inside the mold is shown in Fig. 3.

The rate of change of the enthalpy of the mold, cover, and heater versus the time elapsed from the start of the technological process is presented in Fig. 4. Curves of the components of the heat balance of the technological block are presented in Fig. 5.

As one can see from Fig. 2, for the chosen thicknesses of the heat insulating materials the glass-kremnezit production

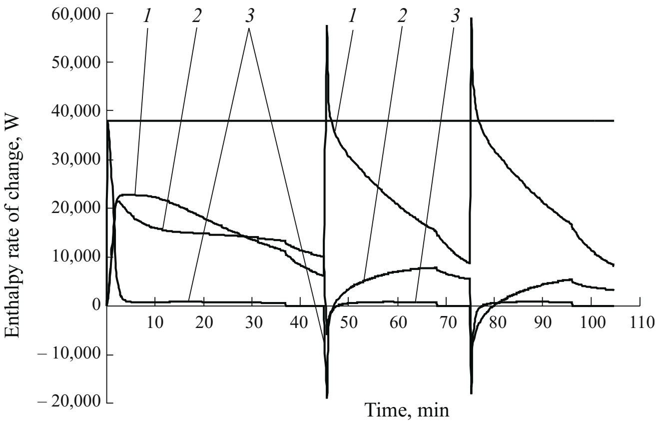


**Fig. 4.** Change of the enthalpy of the mold (*1*), cover (*2*), and heater (*3*) versus the time elapsed from the start of the technological process.

time for initial heating is 45 min. Subsequently, this time reaches a constant value equal to 30 min and does not change when new cars with molds are heated. The heat losses into the surrounding atmosphere do not exceed 0.81 kW, and the temperature of the exterior surface of the heat insulation does not exceed 80°C.

In summary, a technology and a facility for cost-effective fabrication of glass-kremnezit based on modular production have been developed.

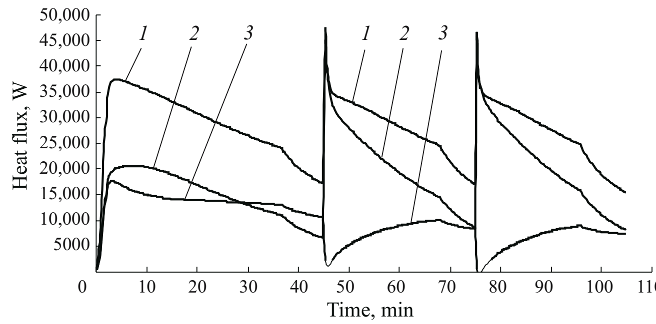


**Fig. 5.** Components of the heat balance of the technological block: *1*, *2*, and *3*) $Q_h$, $Q_m$, and $Q_c$, respectively.

A mathematical model for calculating heat transfer was proposed. This model makes it possible to determine the required thicknesses of the thermal insulation for the covered heater and the molds which give the lowest possible heat losses into the surrounding atmosphere while the heater is continually operating.

## REFERENCES

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